### Managing Manure Nutrients Through Multi-crop Forage Production

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### **ABSTRACT**

Concentrated sources of dairy manure represent significant water pollution potential. The southern United States may be more vulnerable to water quality problems than some other regions because of climate, typical farm size, and cropping practices. Dairy manure can be an effective source of plant nutrients and large quantities of nutrients can be recycled through forage production, especially when multi-cropping systems are utilized. Linking forage production with manure utilization is an environmentally sound approach for addressing both of these problems. Review of two triplecrop systems revealed greater N and P recoveries for a corn silage-bermudagrass hay-rye haylage system, whereas forage yields and quality were greater for a corn silage-corn silage-rye haylage system, when manure was applied at rates to supply N. Nutrient uptake was lower than application during the autumn-winter period, and bermudagrass utilized more of the remaining excess than a second crop of corn silage. Economic comparison of these systems suggests that the added value of the two corn silage crop system was not enough to off-set its increased production cost. Therefore, the system that included bermudagrss demonstrated both environmental and economic advantages. Review of the N and P uptake and calculated crop value of various single, double, and triple crop forage systems indicated that the per hectare economic value as well as the N and P uptakes tended to follow DM yields, and grasses tended to out-perform broadleaf forages. Taken across all systems, systems that included bermudagrass tended to have some of the highest economic values and uptakes of N and P. Manure applied at rates to supply N results in application of excess P, and production will not supply adequate quantities of forage to meet the herd's needs. Systems that lower manure application and supply supplemental N to produce all necessary forage under manure application will likely be less economically attractive due to additional costs of moving manure further and applying it to greater land areas, but will be environmentally necessary in most cases. Intensive forage systems can produce acceptable to high quality forage, protect the environment, and be economically attractive. The optimal manure-forage system will depend on the farm characteristics and specific local conditions. Buffers and nutrient sinks can protect streams and water bodies from migrating nutrients and should be included as a part of crop production systems.

(**Key words:** manure, forages, water quality, riparian buffers)

**Abbreviation key: CCR** = corn silage-corn silage-rye haylage triple crop forage system, **CBR** = corn silage-bermudagrass hay-rye haylage triple crop forage system, **NMP** = nutrient management plan.

### INTRODUCTION

As is true over most of the United States, dairy, live-stock, and poultry production in the southern United States have concentrated into units with greater animal numbers and, regardless of unit size, in localities with specialized infrastructure (Pagano and Abdalla, 1994; Blayney, 2002). This production is often on farms of relatively limited acreage or suitability for extensive manure distribution, increasing the difficulty of assuring sustainable water quality (Short, 2000). As an example, Knutson, et al. (1996) reported that their study dairies in FL, GA, and TX had an average of 665 cows on an average of 140 ha. The situation is intensified by the climate over much of the southern United States. While this climate provides some agricultural advantages, rainfall levels over much of the region create

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potential non-point source environmental problems in the handling and use of manures.

Even though there are major concerns with manure nutrient losses to ground and surface waters, manure nutrients and decaying OM are natural components of the environment. These products should ultimately contribute to the production of more plant and animal tissue. Many of our problems have arisen as a result of a failure to critically credit manure nutrients when developing soil fertility programs, even on farms having significant livestock populations. Dairy farms are generally in much better position to correct this situation than other animal production enterprises, because of their requirement for large quantities of forage. Dairy farms require large amounts of high quality forage, and that is more difficult to produce in the southern United States because of climatic effects on the selection of forages and direct effects on plants. Forage production removes and recycles more nutrients from the soil than other crop alternatives, especially when plants of high nutrient value for cattle are appropriately removed to capture this value. Efficient production of forage, using animal manure, strengthens the economic position of the region for ruminant production and limits the potential negative impact of animal agriculture on the environment.

Even under systems and management that make maintenance of the environment and efficient utilization of manure nutrients a priority, some escape of nutrients is inevitable. For example, even when a triple crop system received deficient applications of N, the N that could not be accounted for was similar to that for adequate N application (Newton et al., 1994). Any manure utilization scheme or plan that does not recognize the need to deal with nutrients leaving the field or production area is incomplete (Lowrance et al., 1985). Landscape features, such as vegetated filter strips (Sanderson et al., 2001) and riparian forests (Lowrance et al., 1984; 1995; Peterjohn and Correll, 1984) can potentially be coupled with production systems to reduce environmental risks of escaped nutrients and provide other benefits at the same time.

### **ENVIRONMENTAL IMPACT OF DAIRY MANURE**

Animal manure, including that from dairy cattle, contains significant amounts of the primary nutrients (N, P, and K) as well as other essential plant nutrients and is an excellent nutrient source for crops (Bartholomew, 1928; Salter and Schollenberger, 1939). However, if excess amounts of manure are applied beyond the use capacity of the crops and holding capacity of the soil or if manure is improperly applied, losses by surface runoff and leaching can contribute to eutrophication of surface

water bodies or contamination of groundwater (Mulla et al., 2001). Problems with dairy cattle manure also may occur from overflow, spills, or lagoon leakage (Mulla et al., 2001). A comprehensive review of the literature concerning the effects of animal agriculture on water quality, including an over 1000 page summary, has been prepared by the University of Minnesota (MEQB, 2002), and sources of information are available which describe manure management from production (Van Horn et al., 1996) through collection and treatment (Moore and Hart, 1997; Grudenmeyer and Cramer, 1997), including land application (Hart et al., 1997), odor (Miner, 1997), public health (Pell, 1997), and economics (Boggess et al., 1997). In addition, there are active programs in many of the individual states to develop training materials and distribute information tailored to local manure management situations (for example, AWARE, 2003).

The potential for nutrient contamination of water from manure sources in the southern United States relative to other regions can be easily visualized by drawing east-west lines across (at the level of northern Maryland and again at northern North Carolina) the series of animal manure nutrient production-crop nutrient utilization and priority subregion maps developed by USDA/NRCS (Kellogg, 2000; Kellogg et al., 2000). A majority of counties that have manure N or P available nearly equal to or greater than crop nutrient requirements are located south of either line. Examination of the data used in projecting manure nutrient excesses reveals that, in the southern United States, low nutrient utilization is as much a part of the potential problem as manure nutrient production. In 1996, 35% of the accessed stream miles impaired by nutrients in the United States were located in the Southeast and South Central regions (NRCS, 1997). Although only a relatively few counties in the southern United States have excess manure nutrients due to dairy cattle populations, and the total amounts of N and P excreted by dairy cattle in the United States have decreased drastically during the past 50 yr (Kellogg and Lander, 1999), dairy cattle are still part of the animal mix contributing to potential water quality problems in the southern United States.

Dairy cattle often spend portions of their time in pasture areas, feeding and lounging barns, and milking parlors. Manure dropped in any of these locations may be of concern. However, unless the stocking rate is too high or cattle are allowed free access to streams, lakes, or ponds, manure dropped in pasture areas may be of less concern than that in barns and milking areas. Manure dropped in barns and parlors is a point source since the land area where it is dropped does not have the capacity to utilize or filter the load. Rainfall-induced

surface runoff from dairy feedlots and holding areas may carry urine and feces into adjacent streams, rivers, or lakes where they have high potential to cause water pollution and contribute to eutrophication. Odor from lagoons, holding ponds, or surface application of manure is also an environmental concern, and mismanagement in the land application of dairy manure has been documented as a cause of water pollution (Odgers, 1991; Hubbard and Lowrance, 1998; MEQB, 2002). Good management is also necessary to avoid runoff or groundwater pollution from manure irrigation, and release of odor and ammonia often occur. (Hubbard and Lowrance, 1998; MEQB, 2002)

A major environmental concern with land application of manure is potential contamination of surface waters and groundwaters with excess N and P. Heavy manure applications have been linked to eutrophication of surface water bodies (Hubbard and Lowrance, 1998). Phosphorus is the primary cause of eutrophication, although N may contribute. Hubbard et al. (1987) reported that as application rates of dairy manure increased, proportionately more N was lost by surface runoff than by leaching. Dairy manure applied to the soil surface is also immediately available for movement by surface runoff, particularly if it has been applied to water saturated or frozen land (Hubbard and Lowrance, 1998). Nitrate leaching is the primary concern for groundwater contamination. Both Hubbard et al. (1987) and Sewell (1975) observed NO<sub>3</sub>-N leaching to shallow groundwater where excess quantities of dairy manure were applied.

Surface water or groundwater can also be contaminated when manure is not over-applied but commercial fertilizers are applied to the same land without accounting for the manure nutrient value, or manure is applied when weather conditions favor runoff (Mulla et al., 2001). Another contributing cause to potential environmental contamination from dairy manure is the need to remove the material frequently. Milking and feeding areas must be cleaned daily, and once holding tanks or lagoons are full, the material within them must be applied to land regardless of weather, soil, or crop conditions.

In the past, many farmers thought of manure as a waste, so manure was often disposed of without careful attention to matching crop, soil, and environmental constraints. Fortunately this is changing rapidly, but the legacy of past over application of manure, especially related to soil P levels, may be an unforseen constraint for some time. Regulatory emphasis will soon be in place aimed at assuring that cropping systems make efficient use of manure nutrients (USEPA, 2002). While such regulation will restrict manure application rates in some cases, it is unlikely that manure nutrient appli-

cation will be restricted below documented crop removal rates except in extreme situations. The economic consequence of developing nutrient management plans (**NMP**) may actually be positive for some farms (VanDyke et al., 1999).

# QUALITY FORAGE IN THE SOUTHERN UNITED STATES

Large quantities of digestible forage are needed to provide the effective fiber and a portion of the energy and protein required by the high producing dairy cow. As forage quality increases, greater proportions are digested in the rumen, increasing passage rate that allows for greater intake. Oba and Allen (1999) reported a 0.17 kg increase in DMI and 0.23 kg increase in milk yield for each one unit increase in forage NDF digestibility. Along with increased performance, diets based on high quality forage are associated with more desirable ruminal fermentation and overall animal health. As forage quality increases and greater quantities of forage are fed, total feed cost typically declines.

Corn silage is the primary forage used in dairy rations in the southeastern United States. In the Coastal Plain, annual ryegrass, oats or other cereal grains, bermudagrass, forage sorghum, and millet are commonly grown in addition to corn silage or as a replacement for corn silage if irrigation is not available. Grazing is primarily limited to winter annual forages due to heat stress unless supplemental cooling can be provided, although some producers have successful grazing programs based on improved bermudagrass varieties such as Tifton 85 (Hill et al., 2001). In the Piedmont, cool season forages such as orchardgrass, fescue, alfalfa, and clover are commonly used for grazing and hay production to supplement corn silage. Annual forages used for pasture include sorghum-sudan hybrids, millet, and most winter annuals (Ball et al., 1996).

Producing high quality forage in the southern United States is a challenge due to high environmental temperatures and drought stress. High environmental temperatures reduce leaf to stem ratio resulting in higher concentrations of NDF and lignin (Buxton et al., 1995). For each 1°C increase in temperature it is estimated that forage digestibility decreases 0.3 to 0.7 percentage units (Buxton et al., 1995). Furthermore, high environmental temperatures cause a more rapid decline in forage quality as forages mature (Van Soest, 1994). These effects may be minimized by harvesting at earlier maturity, but this reduces total yield. Total leaf area may be reduced during a drought, but forage digestibility is commonly higher than that observed during wetter growing seasons because of lower lignin concentrations (Buxton et al., 1995). Under prolonged drought condi-

tions, some forage species may go dormant thereby reducing leaf area further that results in lower forage quality (Buxton et al., 1995).

# UTILIZATION OF DAIRY MANURE IN FORAGE PRODUCTION SYSTEMS

Rather than a general review of nutrient management planning, we have chosen to review forage cropping choices and manure nutrient utilization by various forages. We have attempted to restrict our review to results of trials conducted in the southern United States where dairy manure was used as the nutrient source for 2 or more years. Such comparisons provide information that will assist in development of NMP and economically and environmentally sound dairy manure utilization. Nitrogen and P are the nutrients of greatest environmental concern, and although K concentrations in forage can be of cow health concern, data is often lacking.

At Tifton (Newton et al., 2000; Newton et al., 2001), research has investigated the utilization of manure on a frequent, around-the-year basis in an attempt to reduce manure storage and its associated cost and potential for nutrient loss, odor and overflow; maximize recycling of nutrients in crops; and reduce labor demands associated with seasonal manure application. Forage systems were selected to allow the maintenance of vegetative plants on the soil on an essentially continuous basis. The two systems investigated most recently were: a mixture of Abruzzi rye and crimson clover overseeded in the autumn into a Tifton 44 bermudagrass sod (for spring haylage), minimum tillage silage corn seeded after rye/clover harvest, and bermudagrass hay harvest in summer (CBR); and conventional minimum tillage (no living cover crop) rye and clover established in the autumn (for haylage), a first crop of temperate corn in spring and a second crop of tropical corn in summer (both for silage; CCR). These systems were investigated at field scale under a pivot irrigation system and in replicated small plots, and included comparisons between manure and commercial fertilizer that was applied at rates based on soil tests following each crop. With liquid dairy manure as the only nutrient source, DM yields over 4 yr averaged 29.3 and 32.5 tonne/ha annually for the CBR and CCR systems, respectively. Manure N and P applications and recoveries in the forages are shown in Table 1. The system including the deep-rooted perennial bermudagrass recovered a higher proportion of the applied N. Nitrate-N concentrations in soil water recovered from suction lysimeters at 0.8 and 1.6 m depth were similar but tended to be slightly greater for the CBR system, suggesting that N losses to water may not be greatly different for the two

systems. Manure P recoveries were about 5% (about 9 kg/ha) greater for the CBR system, but both were unacceptably low for most situations where soil test P levels are above low levels. It is interesting to note that P application rates in this study, using manure where the barn was flushed with lagoon liquid, were approximately double that of previous studies using similar N rates from manure flushed with fresh water. Mean forage K concentrations were 1.57 and 1.35% for the CBR and CCR systems, respectively, with the primary difference being higher K concentrations in bermudagrass than tropical corn. Rye forage contained the highest concentrations of K, which averaged 2.8%, with several individual cuttings having concentrations near 3.2% of DM. Manure application resulted in lower nematode and soil borne fungal disease pressure compared to commercial fertilizer, possibly contributing to an 8% yield advantage for manure compared to fertilizer.

Triple crop, year-round forage systems have also been investigated for dairy manure utilization on manure sprayfields at the University of Florida (Macoon et al., 2002; Woodard et al., 2001; Woodard, personal communication). One system was similar to the CBR system discussed above, except that Tifton 85 bermudagrass was used in place of Tifton 44. Tifton 85 is a higher yielding hybrid with improved digestibility, but propagates with stolons rather than rhizomes, possibly making it less tolerant of the abuse of planting and harvesting additional crops in the sod (Macoon et al., 2002; Woodard et al., 2001). Their other triple crop systems were: corn silage, sorghum silage, rye haylage; and corn silage no-till planted into perennial peanut and rye stubble, perennial peanut hay, and rye haylage. They used three levels of manure-N application, 480, 645, and 845 kg/ha. In addition to the triple crop systems, year-round double crop systems consisting of bermudagrass plus rye and perennial peanut plus rye were included in the study.

Dairy manure has been applied to a wide variety of crops in Texas, while forage quality characteristics and nutrient uptakes were monitored (Muir, 2002; and see references 1 to 9 in Table 2 footnote). A year-round system including Coastal bermudagrass plus small grain or ryegrass was a component of some of these studies.

In an attempt at comparing the various crops and crop systems in a manner that would integrate feed nutrients and yield, the economic values of the various forages were calculated. The value for each forage was calculated based on concentrations of DM, CP, TDN, Ca, and P. Energy values were calculated using equations based on fiber content for each type of forage (Chandler, 1990). Where the required data for performing the calculations was missing, estimated values

Table 1. Manure N and P application and recovery for two systems of year-round forage production.

	Crop season								
	Spring		Summer		Autumn		Total		
Nutrient	Harvest (kg/ha)	Recovery (%) <sup>1</sup>	Harvest (kg/ha)	Reovery (%) <sup>1</sup>	Harvest (kg/ha)	Recovery (%) <sup>1</sup>	Applied (kg/ha)	Harvest (kg/ha)	Recovery (%)
N									_
$\mathrm{CBR}^2$	180.7	103	147.1	$120^{\rm a}$	158.4	59	568	486.2	86 <sup>b</sup>
$\mathrm{CCR}^2$	180.5	115	104.5	61	99.1	43	560	384.1	69
P									
CBR	45.2	$61^{a}$	19	52	22.0	26	196	86.2	44
CCR	46	72	18.1	36	13.1	16	197	77.3	39

<sup>&</sup>lt;sup>1</sup>Percent of that applied during the cropping period.

were used, primarily from forage variety trials within the same state. Reference feeds and their summer 2002 market value (\$/tonne) were corn (\$127), soybean meal (48% CP, \$260), dicalcium phosphate (\$463), and limestone (\$66). These values were then multiplied by the reported yields to arrive at the per hectare value of the products of the various systems. These values, along

with the reported DM yield and N and P uptake levels, are shown in Table 2.

Some care should be taken in relying on the comparisons in Table 2, since many of these summarized results are not based on side by side comparisons. In addition, since the values are not based on actual feeding trials, some factors, including palatability, are not taken into

Table 2. Comparisons of forages fertilized with dairy manure for yield, value, and N and P uptake.

	Irrigated	DM yield (tonne/ha)	Crop ratio	Forage value (\$/ha)	Nutrient harvest		
Crop or system					N (kg/ha)	P (kg/ha)	$Reference^1$
Single Crops							
Coastal bermudagrass	No	10.3	100	1220	285	69	1, 2
Coastal bermudagrass	Yes	16.7	100	2022	300	38	2, 3
Kenaf	No	3.7	100	472	52	6	4, 5
Kenaf	Yes	13.8	100	2081	325	29	6
Forage sorghum	Yes	12.8	100	1417	120	16	7
Sorgo-sudan	Yes	16.6	100	1859	191	26	7
Pearl millet	Yes	12.8	100	1382	145	31	7
Grain sorghum	Yes	9.3	100	1141	124	19	7
Napier hybrid	Yes	11.7	100	1319	159	26	7
Corn	Yes	18.6	100	1959	274	46	8, 9
Buffalograss	Yes	14.6	100	1457	248		10,11
Sunflower	Yes	5.0	100	655	82	9	6, 9
Lablab	Yes	7.9	100	1164	215	22	6, 9
Cowpea	Yes	2.4	100	387	100	9	6, 9
Double Crops							,
T-85 bermudagrass/rye	Yes	26.5	85/15	3353	465	80	12
Perennial peanut/rye	Yes	18.1	75/25	2443	358	42	12
Coastal bermudagrass/wheat	No	11.3	80/20	1354	275	78	1, 2
Coastal bermudagrass/wheat	Yes	16.5	76/24	2058	310		2, 3
Coastal bermudagras/ryegrass	No	13.9	62/38	1691	200		$2^{'}$
Coastal bermudagrass/ryegrass	Yes	23.6	77/23	3045	340		2, 3
Sorghum-sudan/wheat	Yes/no	18.2	83/17	2077		52	9
Triple Crops							
Corn/sorghum/rye	Yes	26.3	50/35/15	2985	320	60	12, 13
Corn/bermudagrass/rye	Yes	24.6	51/33/16	2963	425	74	12, 14
Corn/Perennial peanut/rye	Yes	18.4	61/15/24	2167	239	43	$12^{'}$
Corn/T. corn/rye	Yes	30.7	57/34/9	3361	380	77	14

<sup>&</sup>lt;sup>1</sup>Reference numbers: 1. Sanderson. and Jones (1997); 2. Chasteen et al. (1994); 3. Sweeten et al. (1994); 4. Muir (2001); 5. Muir (2002); 6. Muir et al. (2001b); 7. Muir et al. (2001c); 8. Muir et al. (1998); 9. Muir et al. (2001a); 10. Springer (2000); 11. Springer (2001); 12. K. R. Woodard, personal communication; 13. Woodard et al. (2001); 14. Newton et al. (2001).

 $<sup>{}^2\</sup>mathrm{CBR} = \mathrm{corn\text{-}bermuda\text{-}rye/clover}; \ \mathrm{CCR} = \mathrm{corn\text{-}corn\text{-}rye/clover}.$ 

<sup>&</sup>lt;sup>a</sup>Crop system  $\times$  year interaction, P < 0.05.

<sup>&</sup>lt;sup>b</sup>Crop system effect, P < 0.05.

account in the value estimates. As can be seen, the per hectare value as well as the N and P uptakes tend to follow DM yields, and grasses tend to out-perform broadleaf forages, but these are by no means perfect correlations. Over time, irrigated forages will produce higher value forage and recycle more nutrients than dryland production. Taken across single, double, and triple crops, systems that include bermudagrass tend to have some of the highest values and recoveries of N and P. While it may not be obvious when viewing Table 2, overseeding bermudagrass with winter forages often does not increase total yearly DM production or nutrient uptake, but average forage quality is generally improved by the practice. Although this indicates that more productive winter forages are needed for manured fields, usually a significant improvement can be achieved by increasing the number of times that winter forage is harvested. For sprayfield systems, it may be necessary to plan manure application areas on winter forage or increase manure storage so that winter application rates are reduced, since winter forages generally remove fewer nutrients than summer crops (or base land area and application rates on winter, with summer forages supplemented with commercial N fertilizer). Such procedures, to store manure or extend winter application area, will likely be necessary where manure must be applied at P rates, unless some additional manure treatment is installed.

The two highest per hectare value systems from Table 2 appear to be double crop corn silage with winter rye and Tifton-85 bermudagrass overseeded with rye, which are essentially equal. However, the production costs associated with these two systems are likely quite different.

# ECONOMICS OF FORAGE PRODUCTION USING DAIRY MANURE

Dairy manure can provide an economical source of N, P, and K for plant growth. Based on assumed values of \$0.66/kg of N, \$1.32/kg of P, and \$0.33/kg of K, Van Horn et al. (1994) found the range in value for N, P, and K in manure to be \$107 to \$146/yr for each cow. Govindasamy et al. (1994) and several authors since (Henry et al., 1995; Wang and Sparling, 1995; Allison et al., 1999) used linear programming models to investigate the role of manure in crop production and reported that the balance between manure nutrient and crop uptake and the balance between crop nutrient and animal use are essential to determine sustainable manure management practices.

Economic theory suggests dairy production decisions should focus on the joint value of milk and the manure that are produced. If the net return to the last unit of manure produced adds to the whole farm income, a greater volume of milk and manure is likely to be produced. Alternatively, if returns from manure disposal are negative, specifically, if disposal costs exceed nutrient benefits, there is an incentive to reduce milk production and therefore the amount of manure produced. However, the net result depends on the organization of individual farms (Lanyon, 1994) and the interrelated manure management decisions (Hoag and Roka, 1995).

Dairy operations that integrate crop and animal production can utilize manure as a plant nutrient source to reduce expenditure on both fertilizer and manure disposal. On the other hand, dairy producers operate under widely differing constraints, such as amount of cropland, crops, and number of crops per year, opportunity to irrigate, local hauling costs to alternative fields, and N versus P application restrictions, in addition to a degree of uncertainty related to the manure nutrient content. In areas where land application exceeds crop requirements, unused nutrients in manure not only represent an economic loss to dairy farmers but can also potentially contaminate surface and ground water.

The feasibility and economic returns of the two multicrop forage production systems using liquid dairy manure and commercial fertilizer as nutrient sources at the University of Georgia Coastal Plain Station, discussed above, were evaluated over 3 yr. Economic analysis was conducted by developing partial enterprise budgets and then utilizing the stochastic dominance criteria to determine which system or systems were economically and environmentally viable for a dairy producer (Somda, 2001). The analyses were based on per hectare of forage and considered manure as a free good (manure collection and storage were charged to the cattle, with only application costs charged to the crop system). Forage values were estimated for each forage each year as shadow prices in least-cost ration formulations, based on sampled nutrient analyses. The prices of commercial fertilizers, pesticides and seed were based on local quotes, whereas irrigation, labor and other production costs were derived from enterprise budgets developed on crop enterprises at the University of Georgia Plains Branch Experiment Station. All management systems used the same combination of herbicides, insecticides, and fungicides to control weeds, insects, and diseases. The major difference between manure and fertilizer arose due to inorganic fertilizer cost and differences in irrigation costs. The irrigation system was used to apply manure and inorganic fertilizers and, because the manure was applied more often than water, irrigation costs were higher for manure application.

The value of temperate corn silage ranged from \$101 to \$160/tonne. Because higher nutrient values per unit

Table 3. Value of forage and production costs for two manure fertilized triple crop systems.

	System								
	CBR <sup>1</sup> forage DM				CCR <sup>2</sup> forage DM				
Crops	Value (\$/ha)	Costs (\$/ha)	Value (\$/tonne)	Costs (\$/tonne)	Value (\$/ha)	Costs (\$/ha)	Value (\$/tonne)	Costs (\$/tonne)	
Spring corn Bermudagrass	1911 751	973 356	134 101	76 55	1880	974	110	58	
Summer corn Rye/clover Total or mean <sup>3</sup>	606 3268	371 1699	134 122	82 68	1078 457 3415	1067 356 2397	100 147 110	105 123 79	

 $<sup>^{1}</sup>CBR = corn-bermuda-rye/clover.$ 

of forage were associated with lower yields, these same values per tonne produced values per hectare of \$1029 to \$706. The rye/clover silage produced the highest value per tonne. The CCR system had the highest value per hectare in 2 of the 3 yr and the highest overall value, \$3268/ha (Table 3).

The annual per hectare carrying capacity of the forage systems were estimated using the same ration formulations as the economic value determinations that also computed the quantity of each forage used per day per cow. The forage quantities per hectare determined the cow days each ration could be fed, and cow days were summed across all rations for each system and year. The CCR system supported 3.2, 10.1, and 10.4 cows/ha over the 3 yr compared to 4.1, 8.2, and 6.2 for CBR. The manure use capacity per system per year was determined by proportion of the milking herd effluent output that was used on each crop and summed for the system. Dairy herd numbers per year provide the basis for relating the efficient quantities of cow-year effluent output. In this study, the average manure effluent application rate was 12.8 cows/ha annually.

The results of the partial budget analysis of 3 yr of data indicated total annual revenue was 13 to 32% higher with manure than with fertilizer. Similarly, net returns to land and management were higher in both cropping systems with manure than with fertilizer application. Application of manure as a substitute of chemical fertilizer generated value-minus-cost about double that for the production systems without manure. The lagoon and delivery system (to the irrigation system) costs approximately \$437/ha annually. Stochastic dominance analysis indicated that value-minus-costs and amount of N and P in runoff water from the cropping systems with manure were first-degree dominant over the systems with commercial fertilizer. Over half the runoff occurred during the winter cropping season when liquid manure was applied during high soil moisture conditions.

The management practices as implemented were proven to be economically profitable but environmentally unsustainable due to P runoff, if edge of field losses are definitive (0.2 kg/ha annually for fertilizer; 0.8 kg/ha annually for manure). One viable alternative is to minimize the application rate of manure on wet soil by expanding the application land area and/or the capacity of the storage facility to contain the unused manure during the winter season. Extending the manure handling and application system 25% would increase the annual costs approximately \$408/ha annually.

Both of the forage systems are capable of producing large quantities of forage with acceptable to high feeding values. The feeding values of the forage favored CCR over CBR cropping system, when manure was used as the nutrient source. However (as can be calculated from data in Table 3), average annual value-minus-cost for manured CBR was \$1569/ha, while for CCR it was only \$1018. This difference was primarily due to the increased cost of establishing an additional annual crop (tropical corn), along with increased pest control costs for the summer corn compared to bermudagrass.

In this study, the land area required to handle the manure on an N basis was less than the land area required for forage production. The analyses as done indicate a relatively low net cost per cow or per unit of milk of handling the manure but the cost would increase if quantities of manure applied were reduced to levels in which the P quantities applied were limited to those removed by the crops.

### **NUTRIENT SINKS AND BUFFERS**

The year-round forage system at the University of Georgia Coastal Plain Station is surrounded on three sides by riparian buffers. The riparian buffer on the north side of the sprayfield was restored in 1991 as part of the integrated landscape experiment that included the forage system studies (Vellidis et al., 1993). Long-

<sup>&</sup>lt;sup>2</sup>CCR = corn-corn-rye/clover.

<sup>&</sup>lt;sup>3</sup>Total per hectare values and costs, yield adjusted averages for per tonne values and costs.

term hydrologic and water-borne nutrient budgets were developed for the restored riparian wetland (Vellidis et al., accepted). Final retention/removal rates for the N contained in the analyzed ions ranged from a high of approximately 78% for nitrate (90+% of total) to a low of 52% for ammonium. Final retention rates for inorganic P and total P were 65 and 66%, respectively. Denitrification losses of N were measured independently from the mass balances (Lowrance et al., 1995). The average annual denitrification rate in the top 24 cm of soil was 68 kg N/ha annually. The denitrification estimate was about 83% of the N retention/removal. The remainder of the N retention/removal and most of the P retention would be accounted for by vegetation uptake and soil storage of N and P. The riparian buffer was a very effective nutrient sink for the N and P coming from the forage production system located upslope. While riparian buffer retention of N and P in water moving from the commercially fertilized areas of this study was not measured, considering the manured portion of the field and the adjoining riparian buffer (with its three fold reduction in P, as discussed above) as a unit system, P losses from the system would be similar to edge of field P losses from the fertilized areas.

Additional manure-related environmental benefits have been documented for forests and shelterbelts. It is well known that trees and vegetation stabilize streambanks, thus reducing erosion during high flow periods (FISRWG, 1998). Appropriately located trees can also reduce odors and nutrients in air down-wind of livestock facilities and manure application fields (Weathers et al., 2001; Colletti and Tyndall, 2002). Dust, ammonia, and odor molecules are reduced by deposition and adsorption at forest edges. These same authors found that even very narrow bands of trees remove some pollutants, but also increase vertical mixing which generally reduces the distance that odors can be detected. Direct economic benefits from trees occur only on the longer term, but properly managed tree harvest from buffers and riparian areas can be accomplished without destroying their water protecting function.

As in other regions, commercial agriculture in the southern United States is most dominant in areas where it was possible to remove fence rows, field borders, and riparian forest to create large fields. Over the recent past, water quality has tended to deteriorate, even in locations where nutrient applications per unit area of crops has not changed drastically. The consolidation of land into larger fields by removing areas that function as nutrient sinks may be a part of the reason for this change.

### **CONCLUSIONS**

Dairy manure has significant potential to cause water pollution, especially when large numbers of cattle are maintained on limited land areas. Nitrogen and P are the nutrients of primary concern, and preventing their movement to surface waters or groundwater should be a primary objective of manure management. Published data suggests that the southern United States may be more vulnerable to water pollution from manure than other regions of the country, partially due to lower plant nutrient uptake per hectare. Increasing nutrient uptake from fields where manure is applied should be a goal. Production of high quality forage for dairy cattle rations is also more difficult in the warmer regions of the country. Multi-crop systems with year-round forage production will help meet the objective of linking increased nutrient uptake with economical production of quality forage. For two triple-crop systems reviewed in detail, N and P recoveries were greater for a corn silagebermudagrass hay-rye haylage system while yields and forage quality were greater for a corn silage-corn silagerve havlage system when manure was applied at rates to supply N. Bermudagrass is apparently capable of retrieving more of the remaining nutrients applied during the lower-uptake, autumn-winter period than a second crop of corn silage. Examination of several single, double, and triple crop systems suggest that the per hectare economic value of the forage produced as well as the N and P uptakes tend to follow DM yields; grasses tend to out-perform broadleaf forages; over time, irrigated forages produce higher value forage and recycle more nutrients than dryland production; and systems which include bermudagrass tend to have some of the higher economic values and recoveries of N and P. Forage systems that produce the highest yields and/or forage quality do not necessarily have the greatest economic advantage, as production costs may negate these advantages. Applying manure based on N normally results in excess application of P, and inadequate forage production to meet the herd's forage needs. Applying manure to the land area needed to produce enough forage for the herd, then supplementing with N, will improve the P balance, but additional measures may be needed. Riparian buffers can produce a fivefold reduction in nitrate concentration and a threefold reduction in P concentration in water moving from manured fields to streams or lakes and should be a component of manure utilization systems, especially in humid regions.

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